NASA CONTRACTOR REPORT 166312

Application of Guided Inquiry System Technique (GIST) to Controlled Ecological Life Support Systems (CELSS)

Henry Aroeste

NASA Purchase Orders A82705B & A89697B
January 1982

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Prepared for
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under Purchase Orders A82705B & A89697B

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CELSS

CONTENTS

I. INQUIRY METHODOLOGY

A. GENERAL DESCRIPTION

The Guided Inquiry System Technique (GIST) is a tested synthesis of three submethodologies long in use. These are a) analytical outlining (relevance tree) in hierarchical form of significant problem aspects, b) brainstorming using relational terms, here provided in systematic individualized programming, and c) the Delphi format wherein individuals on a panel are separately interviewed in an iterative roundrobin.

During the GIST process the collection of relational terms becomes progressively more extensive. The hierarchical system of key terms converges to a detailed "final" form which serves as a graphic representation of the state-of-the-art both with respect to substance and methodology. Any prior gaps in research program orientation should show up in the hierarchy during the process and may then be repaired.

Because of the integration of the "brainstorming" subtechnique, GIST is more thorough, more productive of better ideas, and thus gives better results than inquiry systems previously available. The GIST methodology is applicable in all arenas where a complex problem is faced, and many different viewpoints are to be integrated satisfactorily.

B. PANEL INTERVIEWS

A panel of experts is interviewed by means of a modified Delphi technique. Each panelist is interviewed individually in succession a total of three times. Each session consists of approximately one hour and a half of programmed interaction wherein the panelist is not only asked to use his analytical abilities in organizing and criticising a hierarchical system but also to respond as well to associative brainstorming. The inclusion of the associative aspect has been shown to be an improvement over the standard Delphi technique which has been criticised as leading only to a superficial consensus.

C. PROGRAMMED INTERACTION

The panelist is asked to respond to the hierarchy by means of a series of programmed consideration units. These units consist either of a single hierarchical rubric (term) or the association of two hierarchical rubrics. In either case the modality of time and/or complexity is introduced by asking the panelist to respond briefly or at length, as well as sometimes presenting him with ancillary material such as related key words or references. Other modalities such as priority or preference may also be introduced. The purpose of the programmed interaction is to present to the panelist an accelerated mind simulation regarding the problem at hand. In this connection, it should be noted that routinely asking for the association of the various rubrics in a "brute force" orderly fashion is neither simulative nor stimulative.

D. PANELIST PERSONALITIES; ROLE OF THE FACILITATOR

Indeed, a few panelists tire even of the simulative program in less than the assigned time, while some would be happy to continue indefinitely. The panelist's attitude cannot usually be predicted in advance, and it is the facilitator's (interviewer's) responsibility to attempt to smooth over as best he can any difficult situations. Generally, an initial statement may be useful regarding the type of response sought, i. e., letting the mind go flexible without untoward criticism at an early stage. Especially, if references are employed as associative aids, it should be made clear that they are neither narrowly chosen nor exhaustive but are presented in order to draw the panelist out toward a broader outlook and into a perhaps curious interrelationship which when properly evaluated may later lead to a substantial innovation. The facilitator himself may at a later stage, on reviewing the assorted responses, note a missed associative connection and may report same. He then acts as a quasi-panelist and, of course, during the actual session is not prevented from presenting a suggestive association after the panelist's initial response or after a lack of response.

E. INFORMATION RETRIEVAL

In addition to panel interaction, two sessions of computerized information retrieval through the Lockheed DIALOG system are interspersed between the three rounds of panel interviews. The chosen DIALOG data base represents the world mind outside the collective panelist mind and is a check therefore on the panel's deliberations. Generally, the prospect of projected information retrieval tends to make the initial panel interviews more concrete than they would be otherwise, and the actuality of retrieved information in the further rounds also aids in this respect. Similarly, the process of information retrieval is assisted through the consultation of panel members.

II. HIGHER PLANTS IN CELSS

A. PANEL

Panel members were Olle Bjorkman, Carnegie Institution; Cary Mitchell, Purdue University; David Raper, North Carolina State University; Frank B. Salisbury, Utah State University; and Leonard P. Zill, NASA Ames Research Center. Ray Huffaker, University of California at Davis, substituted for Olle Bjorkman at the second of three scheduled sessions. All interviews were conducted by telephone except for those with Bjorkman and Zill, which were conducted in person. David Raper's second session was also conducted in person.

B. HIERARCHICAL OUTLINE

The outline (Figure 1) presented herein was the sixth modification of the original outline used at the inception of the panel interviews. Consensus as to the rubrics (terms) of the outline was reached largely by the end of the second round of interviews. Only minor changes occurred thereafter. As rated by the panelists, the rubrics toward the top of the outline or within any section therein are generally more important than lower rubrics; or if rated of approximatley equal importance, then the higher of the rubrics are deemed to have earlier priority. There was general consensus at least through the single-decimal rubrics; however, many of the ratings for the double-decimal rubrics remained unresolved.

- Higher Plants in CELSS
  - 1. Plant
    - 1.1 Physiological
      - 1.11 Photosynthesis
      - 1.12 Biosynthesis
      - 1.13 Respiration
      - 1.14 Transport
    - 1.2 Developmental
      - 1.21 Vegatative Growth
      - 1.22 Reproductive Growth
      - 1.23 Germination
      - 1.24 Turnover Rate
    - 1.3 Species Selection
      - 1.31 Human Nutrition
      - 1.32 Productivity
      - 1.33 Partitioning Ratio
      - 1.34 Antagonisms
    - 1.4 Size
      - 1.41 Leaf Area Index
      - 1.42 Shoot Length
      - 1.43 Canopy Density
      - 1.44 Root Density
  - 2. Input
    - 2.1 Energy
      - 2.11 Radiation Level
      - 2.12 Radiation Quality
      - 2.13 Daylength
      - 2.14 Temperature
    - 2.2 Nutrients
      - 2.21 Carbon
      - 2.22 Nitrogen
      - 2.23 Other Macronutrients
      - 2.24 Micronutrients
    - 2.3 Atmosphere, Gravity
      - 2.31 Composition
      - 2.32 Wind
      - 2.33 Pressure
      - 2.34 Weightlessness
    - 2.4 Water
      - 2.41 Humidity
      - 2.42 Quality
      - 2.43 Plant Water Status
      - 2.44 Nutrient Water Status
  - 3. Output
    - 3.1 Food
      - 3.11 Nutrition Requirements (See 1.31)
      - 3.12 Safety, Reliability
      - 3.13 Acceptability
      - 3.14 Stability
    - 3.2 Air
      - 3.21 Oxygen
      - 3.22 Carbon Dioxide
      - 3.23 Common Pollutants
      - 3.24 Volatiles
    - 3.3 Solid Waste
      - 3.31 Wet Oxidation
      - 3.32 Pyrolysis
      - 3.33 Biological Oxidation
      - 3.34 Mineralization
    - 3.4 Liquid Waste
      - 3.41 Transpiration
      - 3.42 Water Reclamation
      - 3.43 Mineralization
      - 3.44 Evaporation
  - 4. System
    - 4.1 Goals
      - 4.11 Knowledge: Long, Manned Missions
      - 4.12 Knowledge: Stable, Autonomous Systems
      - 4.13 Development
      - 4.14 Mission
    - 4.2 Control
      - 4.21 Characterization
      - 4.22 Strategy
      - 4.23 Measurement
      - 4.24 Safety, Reliability
    - 4.3 Integration
      - 4.31 Compatibility
      - 4.32 Compartmentation
      - 4.33 Constraints
      - 4.34 Implementation
    - 4.4 Management
      - 4.41 Communication
      - 4.42 Planning
      - 4.43 Coordination
      - 4.44 Control

Figure 1. Hierarchy for Higher Plants in CELSS

C. IDEAS/RECOMMENDATIONS

Because of panel limitations regarding knowledge of Output and System, the suggestions noted herein are largely restricted to the first two grand sets of the outline, i.e., Plant, and Input.

1) Morphogenesis may be helpful to develop plants appropriate to CELSS; the use of chemical, perhaps also mechanical, regulators is recommended.

2) Compartmentation may be necessary between plants and humans, as well as between plant species.

3) Senescing plant parts should be removed to increase productivity.

4) Micronutrient toxicities may affect plant growth.

5) Air velocity is a complex factor requiring study (air composition, vibration, cooling).

6) There is a possibility of "rain" because of the large amount of transpiration.

7) Interviews with actual vegetarians, especially vegans, may be helpful.

8) Plants are much less fussy than humans regarding water quality.

9) It is beneficial to decrease shoot length and increase leaf area index; many crops have been developed through genotypes appropriately chosen.

10) Gamma-ray radiation in space should be considered.

11) Plants are subject to auto-intoxication through root discharges.

12) The development of long, spindly stems may be a problem in weightlessness.

13) Air velocity strengthens the stem and provides gas exchange for the leaf.

14) Respiration is a limiting factor at "night".

15) Experts knowledgeable for specific crops should be consulted regarding both productivity and nutritional value.

16) Root temperature may be a critical factor (water utilization).

17) Natural conversion to nitrites may be dangerous.

18) Systems can probably be designed to compensate for weightlessness.

19) Osmolality of nutrient solutions should be monitored.

20) Further research is required regarding leaf area index with respect to saturation and optimization.

21) High light levels are recommended until temperature causes damage (varies with species).

22) Humidity should not be either too high or too low: small leaves will result; a ballpark figure is 70%.

23) Plants in C_3 and C_4 categories should be separated because higher temperatures and light levels are better for C_4 plants; also, if C_3 and C_4 plants are in the same enclosure, the C_4 plants scavenge carbon dioxide, and the C_3 plants die.

24) Both carbon dioxide level and light level have to be increased together to affect photosynthesis optimally.

25) Temperature of plant tissue should also be measured.

26) It may be necessary for plant volatiles to be scrubbed out in order to increase growth.

27) There is need for consideration regarding pollenation: are only self-pollenating plants to be chosen? Wind? Bees?

28) A mixture of lamps will be required to obtain all necessary wavelengths.

29) Too high a leaf area index or canopy density may cause productivity and also nutritional value to decrease.

30) Pressure reduction may be interesting: maintaining carbon dioxide level and lowering oxygen pressure enhances outgassing of volatiles; also, there would be less leakage through the vehicle hull.

31) Productivity should be kept in perspective: merely increasing primary productivity may not be appropriate; increasing secondary productivity of traditional plants may be more significant with food technology as currently practiced or extrapolated; probably, both outlooks in combination may be most appropriate until the future decides.

32) Biosynthesis is key for nutritional value.

33) Weightlessness may be critical; suggest using centrifugal force.

34) Plant interactions broader than antagonisms should be considered (competition, mutualism).

35) Root density may be a limiting factor, after other more obvious factors are optimized.

36) Optimize macronutrient balances for each species.

37) If daylength is too high, stem elongation may be too much increased.

38) It is suggested that the outline rubrics relating to size may not be appropriate to CELSS; an index based on bulk volume may be more useful.

39) Radiation quality may serve as a controller of productivity.

40) The ability of plants to tolerate ammonium (ammonia) should be a subject of investigation.

41) Does presence of another plant affect germination? The area around a walnut tree is an example of negative effect.

42) Lack of wind leads to tall, spindly plants; wind promotes lignin production useful to strength.

D. INFORMATION RETRIEVAL

The strategy for information retrieval is given in the following printout labelled RECALL 5032. In this strategy the symbol, # is SELECT; the notation, ? ? is used so as to yield plurals as well as singulars; (W) signifies that words to the left and right of (W) appear in text as stated; S is for set; and the symbol, * is AND. Sets 1-13 are preliminary reference sets for which no citations are intended to be obtained. Table 1 gives the detailed relationship between the remaining sets and the hierarchical rubrics.

The strategy has been applied to AGRICOLA Lockheed DIALOG files 10 and 110. The results have been presented on magnetic tape and are also available in typed printout. The same strategy has been applied to BIOSIS Lockheed DIALOG files 5 and 55, as well as to CAB ABSTRACTS Lockheed DIALOG file 50. These latter are available only in typed printout. A sample page of citations in file 110 follows the strategy printout.

Table 1

HIERARCHICAL REBRICS/INFORMATION RETRIEVAL SETS

Rubric	Set	Rubric	Set	Rubric*	Set
1.11	14	2.11	30	3.1	47
1.12	15	2.12	31	3.2	48
1.13	16	2.13	32	3.3	49, 50
1.14	17	2.14	33	3.4	49, 51
1.21	18	2.21	34	4	52- 55
1.22	19	2.22	35		
1.23	20	2.23	36		
1.24	21	2.24	37		
1.31	22	2.31	38, 39		
1.32	23	2.32	40		
1.33	24	2.33	41		
1.34	25	2.34	42		
1.41	26	2.41	43		
1.42	27	2.42	44		
1.43	28	2.43	45		
1.44	29	2.44	46		

*Rubrics 3 and 4 are not fully detailed because of panel limitations.

```
  .RECALL 5032
Line Set Command
   1    1   # PLANT? ?
   2    2   # PHYSIOLOGICAL
   3    3   # CROP? ?
   4    4   # RADIATION
   5    5   #NUTRIENT? ?
   6    6   # SUBSTRATE? ?
   7    7   # CARBON(W)DIOXIDE
   8    8   # AIR
   9    9   # POLLUTANT? ?
  10   10   # FOOD(W)PRODUCTION
  11   11   # ATMOSPHERE? ?
  12   12   # SYSTEM? ?
  13   13   # HUMAN(W)NUTRITION
  14   14   # S1*S2*PHOTOSYNTHESIS
  15   15   # S1*S2*BIOSYNTHESIS
  16   16   # S1*S2*RESPIRATION
  17   17   # S1*S2*TRANSPORT
  18   18   # S3*VEGETATIVE(W)GROWTH
  19   19   # S1*REPRODUCTIVE(W)GROWTH
  20   20   # S1*GERMINATION*MATURATION
  21   21   # S1*TURNOVER(W)RATE? ?
  22   22   # S3*S13*SPECIES
  23   23   # S1*PRODUCTIVITY*SPECIES
  24   24   # PARTITIONING*RATIO? ?
  25   25   # S3*ANTAGONISM? ?
  26   26   # S1*LEAF(W)AREA(W)INDEX
  27   27   # SHOOT(W)LENGTH
  28   28   # CANOPY(W)DENSITY
  29   29   # ROOT(W)DENSITY
  30   30   # S1*S4*LEVEL? ?
  31   31   # S1*S4*QUALITY
  32   32   # S3*DAYLENGTH? ?
  33   33   # S1*S4*TEMPERATURE
  34   34   # S1*S5*CARBON
  35   35   # S3*S5*NITRATE? ?
  36   36   # S1*MACRONUTRIENT? ?
  37   37   # S6*MICRONUTRIENT? ?
  38   38   # S1*S7*S11
  39   39   # S1*S8*OXYGEN
  40   40   # S1*S8*WIND? ?
  41   41   # S1*S8*PRESSURE
  42   42   # S1*WEIGHTLESSNESS
  43   43   # S1*WATER*HUMIDITY
  44   44   # S1*S9*WATER(W)QUALITY
  45   45   # WATER(W)STATUS *S1 *WATER(W)
         POTENTIAL
-more-
? P
Line Set Command
  46   46   # S5*WATER(W)STATUS
  47   47   # S1*S3*S10
  48   48   # S1*S3*S11
  49   49   # S3*WASTE(W)MANAGEMENT
  50   50   # S3*SOLID(W)WASTE
  51   51   # S3*LIQUID(W)WASTE
  52   52   # S1*SPACE(W)BIOLOGY
  53   53   # S3*S12*ECOLOGY
  54   54   # S3*S12*MANAGEMENT*CONTROL? ?
  55   55   # CLOSED*ECOSYSTEM? ?
?
```

30/3/9
992741 442.8 Z6 ID No: 75-9070519
On the biological effect of an increased ionizing level of radiation and the processes of radioadaptation in populations of herbaceous plants
Cherezhanova, L V; Aleksakhin, R M
Zh Obshch Biol 36 (2): 303-311. Ref. Eng. sum. Mar/Apr 1975

31/3/1
601464 80 H7892 ID No: 72-9074915
Effects of radiation, day-length and temperature on plant growth and quality: a preliminary report
Hardh, J E; Hardh, K
Hort Res 12 (1): 25-42. Ref. May 1972

31/3/2
154160 22.5 C88 ID No: 70-9055967
Studies on dry matter production of soybean plant. VI. Changes in spectral composition of solar radiation penetrating through leaf canopy and photosynthetic rate of single leaf as affected by light quality
Kumura, A
Crop Sci Soc Japan Proc 38 (3): 408-418. Sept 1969

31/3/3
124260 470 C16C ID No: 70-9024651
The quality of short-wave radiation within plant canopies
Daynard, T B
Can J Bot 47 (12): 1989-1994. Dec 1969

? T 32/3/1-2;T 33/3/1-8;T 34/3/1-8
32/3/1
1163590 104 D41A ID No: 76-9094511
Senility problem in the greenhouse cucumber (Cucumis sativus) crop: effect of daylength on yield and content of abscisic acid-like growth inhibitors
Bredmose, N; Andersen, A S
Arsskr K Vet Landbohojsk p. 31-44. Ref. 1975

32/3/2
695718 442.8 B5264 ID No: 73-9153798
Changes in photosynthetic products of crop plants under different cultivation condition conditions by 14Co .carbon dioxide. assimilation of barley plant grown at different daylength and nutrition
Shiomi, N; Hori, s
Biol Sci 24 (3): 144-150. Ref. Dec 1972

33/3/1
1466146 80 AC82 ID No: 78-9108553
The aromatic compounds of spice plants in Nordic environment .Temperature, day length, radiation.
Hardh, J E
Acta Hortic 73: 269-271. May 1978

33/3/2
1143167 451 B775 ID No: 76-9076454
Soil reflection coefficient and its consequences for soil temperature and plant growth .Radiation balance.
Watts, W R
Symp Br Ecol Soc 16th: 409-421. Ref. 1974 (pub. 1975)

33/3/3
850297 60.9 J27 ID No: 74-9050772
Dry matter production of forage plants. XII. Influence of air temperature and radiation on the seasonal dry matter production of orchardgrass .Dactylis glomerata. sward in Japan
Kubota, F; Agata, W; Kamata, F

III. NUTRITION AND FOOD PROCESSING FOR CELSS

A. PANEL

Panel members were Peter Clark, Epstein Process Engineering, Inc.; Sanford Miller, Bureau of Foods, FDA; Howard Moskowitz, Moskowitz/Jacobs Inc.; and Vernon Young, Massachusetts Institute of Technology. All interviews were conducted by telephone.

B. HIERARCHICAL OUTLINE

Consensus as to the rubrics (terms) of the outline (Figure 2) was reached by the end of the second round of interviews. The rubrics toward the top of the outline or within any section therein are generally more important than lower rubrics; or if rated of approximately equal importance, then the higher of the rubrics are deemed to have earlier priority. Numbers in parenthesis in Figure 2 refer to information retrieval sets as discussed in Section III.D.

C. IDEAS/RECOMMENDATIONS

1) Imbalances must be carefully monitored; for example, too much zinc may cause reduced copper absorption; too much calcium may reduce zinc or magnesium absorption.

2) Largely unknown nutritional factors related to space are stress, long term, zero gravity effects on human physiology, metabolism.

3) Possible space conversion problems stem from zero gravity, compactness, resupply, repair, remoteness.

4) Zero gravity may have effects on lipid metabolism, calcium absorption (bone mineral density).

5) Combinations of various genetically designed plants or of designed and conventional plants may prove useful, whereas single designed plants may not be.

6) Synthesis from human waste products may yield a nonspecific nitrogen source.

7) Monotony (lack of food variety) may be a long-term space problem.

8) Use of unconventional foods requires consideration, as they often lead genetically to curious physiological reactions.

9) The unconventional plants have a better chance of utilization in space before other unconventional foods.

10) Unconventional foods must meet nutrition and acceptance standards.

11) Most so-called unconventional plants may not be considered unconventional in certain societies.

- Nutrition and Food Processing for CELSS
  - 1. Nutrition Requirements
    - 1.1 Energy Sources
      - 1.11 Simple Carbohydrates (17)
      - 1.12 Complex Carbohydrates (18)
      - 1.13 Triglyerides (19)
      - 1.14 Other (20)
    - 1.2 Organic Nutrients
      - 1.21 Essential Amino and Fatty Acids (21, 22)
      - 1.22 Nonspecific Nitrogen Sources (23)
      - 1.23 Fat Soluble Vitamins (24)
      - 1.24 Water Soluble Vitamins (25)
    - 1.3 Inorganic Nutrients
      - 1.31 Electrolytes (26)
      - 1.32 Macrominerals (27)
      - 1.33 Trace Minerals (28)
      - 1.34 Water (29)
    - 1.4 Nutritional Values
      - 1.41 Bioavailability (30)
      - 1.42 Protein Quality (31)
      - 1.43 Nutrient Interactions (32)
      - 1.44 Other (33)
  - 2. Acceptance
    - 2.1 Physical Sensory Properties
      - 2.11 Taste (34)
      - 2.12 Smell (35)
      - 2.13 Texture (36)
      - 2.14 Appearance (37)
    - 2.2 Food Habits
      - 2.21 Consumption Patterns (38)
      - 2.22 Time Preference (39)
      - 2.23 Food Combinations (40)
      - 2.24 Measurement Methods (41)
    - 2.3 Dietary History
      - 2.31 Cultural Background (42)
      - 2.32 Eating Style (43)
      - 2.33 Idiosyncratic Cravings (44)
      - 2.34 Idiosyncratic Reactions (45)
    - 2.4 Physiological/Nutritional Needs
      - 2.41 Hunger (46)
      - 2.42 Dietary Requirements(47)
      - 2.43 Illness Impacts (48)
      - 2.44 Thirst (49)
  - 3. Unconventional Foods
    - 3.1 Plants
      - 3.11 Legumes (50)
      - 3.12 Seeds, Nuts(51)
      - 3.13 Grasses, Leaves (52)
      - 3.14 Tubers, Roots (53)
    - 3.2 Micro-organisms
      - 3.21 Bacteria (54)
      - 3.22 Fungi (55)
      - 3.23 Algae (56)
      - 3.24 Yeasts (57)
    - 3.3 Chemical Synthesis
      - 3.31 Carbohydrates/Energy Sources (58)
      - 3.32 Fats, Fatty Acids (59)
      - 3.33 Amino Acids (60)
      - 3.34 Polypeptides (61)
    - 3.4 Miscellaneous
      - 3.41 Animals (62)
      - 3.42 Genetic Engineering (63)
      - 3.43 Tissue Cultures (64)
      - 3.44 Screening Factors (65)
  - 4. Space Technology Conversion
    - 4.1 Separation
      - 4.11 Size (66)
      - 4.12 Density (67)
      - 4.13 Quality (68)
      - 4.14 Moisture Content (69)
    - 4.2 Refining
      - 4.21 Extraction (70)
      - 4.22 Sterilization (71)
      - 4.23 Dehydration (72)
      - 4.24 Clarification (73)
    - 4.3 Fabrication
      - 4.31 Mixing (74)
      - 4.32 Shaping (75)
      - 4.33 Portioning (76)
      - 4.34 Assembly (77)
    - 4.4 Conversion
      - 4.41 Cooking (78)
      - 4.42 Cooling (79)
      - 4.43 Hydrolysis (80)
      - 4.44 Biological (81)

Figure 2. Hierarchy for CELSS Nutrition and Food Processing

12) Cultural backgrounds of space personnel should not be too different.

13) Unconventional foods should be considered from a cost-benefit ratio viewpoint.

14) Supplements will probably be necessary; recommend balance of natural and artificial foods.

15) Common foods such as bread require efficient production in space.

16) Stress may lead to electrolyte inbalances which in turn affect taste.

17) Different consumption patterns in space require study.

18) Astronauts may be less conventional if highly motivated, but beware of long term; in general, people are risk aversive and favor traditional foods.

19) Manipulated food may be quite satisfactory, e.g., a small coconut grown on a bush may be nutritionally useful.

20) Fats are generally more dense and thus may be useful in space, but consideration must be given to possible lack of exercise.

21) Complex carbohydrates should be adequately available as a rate-controlled energy source.

22) Minerals may be supplied by recycling from waste.

23) Investigate possible prior studies of nuclear submarine environments.

24) Grasses are efficient biomass, but their high cellulose content requires conversion.

25) In a closed environment, persons may turn to food as means to avoid stress, and certain food characteristics such as appearance may become magnified in the mind.

26) Legumes are especially useful in that they are able to fix nitrogen, but they may be difficult to grow in space, unlike grasses; perhaps, "artificial" legumes may be grown.

27) Genetic engineering technology is sufficiently far along to be available for long-term space travel.

28) Food processing activities which depend on gravity may be more difficult, certainly different, but vacuum or low-temperature processes may be easier.

29) Polypeptides may be useful as a rate-controlled amino acid supply to the body.

30) Space limitations in space may preclude large conversion plants; also, chemical engineering expertise may not be available in space if needed for repairs.

31) Of all micro-organisms, fungi offer best possibility of successful utilization in space.

32) Chemical synthesis may be useful as a supplement, especially for amino and fatty acids.

33) Reliable production of food and water is critical, more so than conversion.

34) A low-humidity vehicle may have special problems, e.g., premature dryout of produce.

35) Acceptance of unconventional foods is more of a problem than meeting nutritional requirements.

36) Although production may be critical, conversion in space remains as the lag technologically in space; common mixing processes will not work in space, and a whole new set of machines will be required; recommend shuttle to test.

37) Lesser nutritional factors such as cholesterol are even more unknown in space and require careful monitoring.

38) Biological conversion to form triglycerides may be useful in space because triglycerides may be otherwise unavailable.

39) Interactions of nutrients with drugs may be a unique problem in space and require careful monitoring.

40) Development of unconventional foods may require sterilization or other special processes difficult in space.

41) Astronauts tend to lose calcium and potassium; NASA has research projects regarding these effects.

42) Illness affects food intake and electrolyte balance, and the impact of illness in space must be carefully monitored.

43) Plants all of which may be eaten may be more efficient for space utilization.

44) Processing has to be carefully chosen so as not to overly diminish bioavailability.

45) Cosmic radiation may cause mutations which lead to allergic reactions.

46) Another's eating style may be magnified into a problem in space.

47) Storage may be unbalanced by chemical additions.

48) Algae have thick walls and will require heavy processing.

49) Perception may be altered under space conditions; all psychological experiments performed on earth may have to be repeated in space.

12) Cultural backgrounds of space personnel should not be too different.

13) Unconventional foods should be considered from a cost-benefit ratio viewpoint.

14) Supplements will probably be necessary; recommend balance of natural and artificial foods.

15) Common foods such as bread require efficient production in space.

16) Stress may lead to electrolyte inbalances which in turn affect taste.

17) Different consumption patterns in space require study.

18) Astronauts may be less conventional if highly motivated, but beware of long term; in general, people are risk aversive and favor traditional foods.

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20) Fats are generally more dense and thus may be useful in space, but consideration must be given to possible lack of exercise.

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25) In a closed environment, persons may turn to food as means to avoid stress, and certain food characteristics such as appearance may become magnified in the mind.

26) Legumes are especially useful in that they are able to fix nitrogen, but they may be difficult to grow in space, unlike grasses; perhaps, "artificial" legumes may be grown.

27) Genetic engineering technology is sufficiently far along to be available for long-term space travel.

28) Food processing activities which depend on gravity may be more difficult, certainly different, but vacuum or low-temperature processes may be easier.

29) Polypeptides may be useful as a rate-controlled amino acid supply to the body.

30) Space limitations in space may preclude large conversion plants; also, chemical engineering expertise may not be available in space if needed for repairs.

31) Of all micro-organisms, fungi offer best possibility of successful utilization in space.

32) Chemical synthesis may be useful as a supplement, especially for amino and fatty acids.

33) Reliable production of food and water is critical, more so than conversion.

34) A low-humidity vehicle may have special problems, e.g., premature dryout of produce.

35) Acceptance of unconventional foods is more of a problem than meeting nutritional requirements.

36) Although production may be critical, conversion in space remains as the lag technologically in space; common mixing processes will not work in space, and a whole new set of machines will be required; recommend shuttle to test.

37) Lesser nutritional factors such as cholesterol are even more unknown in space and require careful monitoring.

38) Biological conversion to form triglycerides may be useful in space because triglycerides may be otherwise unavailable.

39) Interactions of nutrients with drugs may be a unique problem in space and require careful monitoring.

40) Development of unconventional foods may require sterilization or other special processes difficult in space.

41) Astronauts tend to lose calcium and potassium; NASA has research projects regarding these effects.

42) Illness affects food intake and electrolyte balance, and the impact of illness in space must be carefully monitored.

43) Plants all of which may be eaten may be more efficient for space utilization.

44) Processing has to be carefully chosen so as not to overly diminish bioavailability.

45) Cosmic radiation may cause mutations which lead to allergic reactions.

46) Another's eating style may be magnified into a problem in space.

47) Storage may be unbalanced by chemical additions.

48) Algae have thick walls and will require heavy processing.

49) Perception may be altered under space conditions; all psychological experiments performed on earth may have to be repeated in space.

50) Chemical synthesis may provide the nutrients required by micro-organisms which in turn may provide biological conversion of necessary foods.

51) Fortified amino acids may be toxic and require metering.

52) Minor dietary factors may be controlled by pills.

53) Recommend systems analysis for complex problem of feeding in space; GIST is an initial step.

54) Study populations which live on monotonous diets.

55) No objection nutritionally to moderate use of alcohol in space; may be advantageous.

56) Recommend fortification to maintain nutrient balance.

57) Supplement amino acid shortfall through synthesis or carry into space.

58) Energy-dense foods may be most useful in space; bulk is especially a problem with carbohydrates.

59) Genetic engineering may be especially useful in providing denser foods.

60) Unconventional animals are more difficult to accept than unconventional plants.

D. INFORMATION RETRIEVAL

The strategy for information retrieval is given in the following printout labelled RECALL 5RQF. See Section II.D. for definition of symbols; in addition, a single ? signifies that all words beginning with what precedes ? are included. Sets 1-16 are preliminary reference sets for which no citations are intended to be obtained. Consult Figure 2, where the set numbers in parenthesis are related to the rubrics as shown.

The strategy has been applied to AGRICOLA Lockheed DIALOG files 10 and 110. The results have been presented on magnetic tape and are also available in typed printout. The same strategy has been applied to CAB ABSTRACTS Lockheed DIALOG File 50, as well as to FOOD SCIENCE AND TECHNOLOGY ABSTRACTS Lockheed DIALOG file 51. These latter are available only in typed printout. A sample page of citations in file 10 follows the strategy printout.

```
 .RECALL SRQF
Line Set Command
   1   1  # NUTRITION
   2   2  # FOOD? ?
   3   3  # HUMAN? ?
   4   4  # S1*S3
   5   5  # S2*S3
   6   6  # HUMAN(W)NUTRITION
   7   7  # ACCEPTANCE
   8   8  # S2*S7
   9   9  # FOOD(W)HABIT? ?
  10  10  # S9*PREFERENCE? ?
  11  11  # DIETARY(W)HISTOR?
  12  12  # HUMAN(W)FOOD? ?
  13  13  # S2*SYNTHE?
  14  14  # UNCONVENTIONAL
  15  15  # S2*PROCESSING
  16  16  # S2*REFIN?
  17  17  # SIMPLE(W)CARBOHYDRATE? ?
  18  18  # COMPLEX(W)CARBOHYDRATE? ?
  19  19  # S6*TRIGLYCERIDE? ?
  20  20  # S6*ALCOHOL? ?
  21  21  # S6*ESSENTIAL(W)AMINO(W)ACID? ?
  22  22  # S6*ESSENTIAL(W)FATTY(W)ACID? ?

? P
Line Set Command
  23  23  # NONSPECIFIC(W)NITROGEN
  24  24  # S4*FAT(W)SOLUBLE(W)VITAMIN? ?
  25  25  # S4*WATER(W)SOLUBLE(W)VITAMIN? ?
  26  26  # S1*ELECTROLYTE? ?
  27  27  # MACROMINERAL? ?
  28  28  # S6*TRACE(W)MINERAL? ?
  29  29  # S6*WATER
  30  30  # S1*BIOAVAILABILITY
  31  31  # S4*PROTEIN(W)QUALIT?
  32  32  # S3*NUTRIENT(W)INTERACTION? ?
  33  33  # S4*DIETARY(W)FACTOR? ?
  34  34  # S8*TASTE? ?
  35  35  # S8*SMELL? ?
  36  36  # S8*TEXTURE? ?
  37  37  # S8*APPEARANCE? ?
  38  38  # S9*CONSUMPTION(W)PATTERN? ?
  39  39  # S10*TIME? ?
  40  40  # FOOD(W)COMBINATION? ?
  41  41  # S9*MEASUREMENT? ?
  42  42  # S11 *CULTURAL
  43  43  # EATING(W)STYLE? ?
  44  44  # CRAVING? ?

? P
Line Set Command
  45  45  # S11*ALLERG?
  46  46  # S8*HUNGER? ?
  47  47  # S1*DIETARY(W)REQUIREMENT? ?
  48  48  # S4*ILLNESS?
  49  49  # S8*THIRST?
  50  50  # S12*SOYBEAN? ?
  51  51  # S1*WINGED(W)BEAN? ?
  52  52  # PLANT(W)LEAF(W)PROTEIN? ?
  53  53  # S5*CASSAVA? ?
  54  54  # S12*BACTERI?
  55  55  # S12*FUNG?
  56  56  # S12*ALGAE
  57  57  # S12*YEAST? ?
  58  58  # S13*CARBOHYDRATE? ?
  59  59  # S13*FAT? ?
  60  60  # S13*AMINO(W)ACID? ?
  61  61  # SYNTHETIC(W)POLYPEPTIDE? ?
  62  62  # S2*S14*ANIMAL? ?
  63  63  # S2*GENETIC(W)ENGINEERING
  64  64  # S2*TISSUE(W)CULTURE? ?
  65  65  # S8*S14
  66  66  # S15*MILLING

? P
Line Set Command
  67  67  # S15*DENSITY
  68  68  # S2*SEPARATION*QUALITY
  69  69  # S15*MOISTURE(W)CONTENT
  70  70  # S15*EXTRACTION
  71  71  # S15*STERILIZATION
  72  72  # S15*DEHYDRATION
  73  73  # S16*CLARIFICATION
  74  74  # S15*MIXING
  75  75  # S15*SHAPING
  76  76  # S15*PORTIONING
  77  77  # S15*ASSEMBLY
  78  78  # S2*CONVERSION*COOKING
  79  79  # S15*COOLING
  80  80  # S5*HYDROLYSIS
  81  81  # BIOLOGICAL(W)CONVERSION
?
```

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-166312		

4. Title and Subtitle	5. Report Date
Application of Guided Inquiry System Technique (GIST) to Controlled Ecological Life Support Systems (CELSS).	January 1982
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Henry Aroeste	
	10. Work Unit No. T5425
9. Performing Organization Name and Address ACCORD 28254 Radcliffe Lane Los Altos Hills, CA 94022	11. Contract or Grant No. P.O. A82705B & A89697B
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered Contractor Final Report
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code 199-60-62

15. Supplementary Notes

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16. Abstract

Guided Inquiry System Technique (GIST), a global approach to problem solving, was applied to the subject of Controlled Ecological Life Support Systems (CELSS). Nutrition, food processing, and the use of higher plants in a CELSS were considered by a panel of experts. Specific ideas and recommendations gleaned from discussions with panel members are presented.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
CELSS Guided Inquiry System Technique Higher Plants Nutrition Food Processing	Unclassified - Unlimited STAR Catergory 54

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	23	

*For sale by the National Technical Information Service, Springfield, Virginia 22161

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